Global Space Exploration Conference (GLEX 2021), St Petersburg, Russian Federation, 14-18 June 2021.

GLEX-2021,3,2,5,x63109

COMPARISION OF AIR-LAUNCHED REUSABLE SYSTEM VS GROUND-LAUNCHED SYSTEM FOR MARS SAMPLE RETURN

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Abstract

Sample return missions from the Martian surface have been one of the most ambitious endeavours for many space agencies, yet there have been no practical trials to accomplish, due to the technical challenges that the missions face. A major setback for these missions is the lack of any possible tested methods to collect the samples and leave the Martian atmosphere. One of the prevailing methods to bring back the collected samples would be to use a launch vehicle from the Martian surface that would impel the sample carrier out of the atmosphere. The downside of using a launch vehicle is its requirement for fuel and an oxidizer, of which the latter is scarce on Mars, hence there is a requirement of carrying them from earth. As the above-mentioned problem hinders the mission, the novel idea being proposed here is the use of multiple reusable aerial vehicle systems, that can collect samples from different locations, after which they fly-up, to the maximum possible altitude based upon the Martian atmospheric constraints, and then the samples are propelled from this vehicle using small single-staged propulsion vehicle to dock the payload with the revolving orbiter. Also, these aerial vehicles could be landed back again, thus could be reused for collecting samples multiple times and even for any other Mars exploration purposes. This paper will mainly focus on the comparison of using aerial vehicle system proposed here, with the method of bringing back samples using a launch vehicle from the Martian surface in terms of feasibility, efficiency, economical aspects, etc.

Keywords: Mars Plane; Air launch; Mars Sample Return; Future Mars Exploration; Mars drones; Launch mechanism comparison;

Nomenclature:

L : Lift in Newton

ρ_∞ : free stream Atmospheric Density

v_∞ : free stream Cruise Velocity

A : Wing Area

c_L : Coefficient of lift

L_1 : Lift generated by Massiva

L_2 : Lift generated by the autonomous Air-launch aircraft

A_1 : Wing Area of the Massiva

A_2 : Wing Area of the autonomous Air-launch aircraft

m_1: Total Mass of Massiva, including the payload

m_2 : Total Mass of the autonomous Air-launch aircraft including the mass of the rocket launcher

s : Wingspan of the autonomous Air-launch aircraft

g_m : Acceleration due to gravity on Mars

1. Introduction:

A launch vehicle is a rocket-powered vehicle used for transporting the spacecraft to outer space, which can be either into an orbit around the Earth or to any other destination like planets, moons, etc [1]. Since the beginning of mars exploration, the sample return mission has been its most ambitious phase. The reason for this is the inability of spacecraft instruments to perform critical measurements such as precise radiometric age dating, sophisticated stable isotopic analyses, definitive life-detection assays required to answer the major questions of life on mars, its climate and geology, which would need the state-of-the-art laboratories on Earth [2].

The current method followed for mars sample return involves, Entry Descent and Landing (EDL) through the atmosphere and onto the surface; surface mobility to collect samples; a rocket-powered Mars Ascent Vehicle (MAV) capable of launching the samples into space from the Martian surface; transportation of the sample back to the vicinity of Earth; and EDL of the sample at Earth in a controlled manner to minimize the risk of planetary back contamination at Earth [3].

MAV is the rocket with the main task of returning the collected samples from the Martian surface [4]. It is a two-stage hybrid rocket, where the first stage would be responsible for reaching the target Low Mars Orbit (LMO), and release its payload into the orbit with its upper second stage, which is utilized for orbital circularization [4]. The downside of using a launch vehicle is its requirement for fuel and an oxidizer, of which the latter is scarce on Mars hence there is a requirement of carrying them from Earth. Also, the current proposed model of MAV is not a reusable launch vehicle. In order to address the above-mentioned issues, this paper presents a novel idea of utilizing a reusable aerial vehicle system, that can collect samples and then fly up to the maximum possible altitude based on the Martian atmospheric constraints, and then the sample capsule is air-launched from this vehicle using small single-staged or two-staged rocket-powered vehicle to the target orbit, which would be captured by the revolving orbiter. These aerial vehicles could be landed back again, thus could be reused for collecting samples multiple times and even for other Mars exploration purposes. The proposed idea is evaluated considering the available, proposed designs of aerial vehicles for Martian exploration, which are mentioned in the literature survey section. Among these, the design that could be utilized for the proposed purpose and the required design variations to be done in the selected design to meet the requirements of the Air-launch is also presented. Along the sides, the research paper also focuses on possible methods for reducing the mass of the single or two-staged rocket that could be carried by the aerial vehicle, and the feasibility of using an air-launch system for sample return over the ground launch system is discussed in the paper.

2. Methodology:

2.1. Literature survey of the existing aircraft designs for Martian conditions:

The major requirements for flying an aerial vehicle on mars were to improve the low resolution of the terrain images captured by orbiter for scientific analysis and to increase the area covered by land rovers, though surface analysis was possible. The mars plane would give us the capability of exploring the Martian terrain, also help us reach places that cannot be reached by rovers, thus facilitating us to extract the valuable data from these sites. The capability of a Martian airplane can even be extended to transfer the extracted samples from the surface to the orbit.

Even though the gravity on mars is 0.377 of that on Earth, which is an added advantage, but its atmosphere is just 1% as that on Earth [5] is the major drawback for flight on Mars. To obtain the same lift coefficient on Mars as on Earth, an aircraft must fly 6.14 times faster than on Earth, which would be closer to the speed of sound on mars. Flying an airplane close to Mars datum at high enough subsonic speed to produce the required lift coefficient will require a Reynolds Number of around 150,000, which is very low. With all these design constraints, according to [5], the most reasonable altitude for flight on mars would be around 3 to 4 km above the datum.

A brief description of the existing, proposed designs of aerial vehicles for flight on mars is discussed in the upcoming part of this section.

The first concept for a Mars plane was given by Chirivella, from the Jet Propulsion Laboratory, NASA [6]. The first series of flights referred to as Mini-sniffers was supposed to be powered by a hydrazine engine. They were tested at an altitude of 30 km on Earth, where the atmospheric conditions resembled the Martian atmosphere. There were three mini-sniffer missions. Mini sniffer-I had a wingspan of 5.5 meters (18 feet) and tailfins on the wingtips. It used a gasoline-powered piston engine and performed several low-altitude flights to validate the design. In the Mini sniffer-II design, the previous was modified by replacing the canards and the wingtip tailfins with tail booms and also by extending the wings, providing it a wingspan of 6.7 meters (22 feet). It was still powered by a gasoline engine and made 21 flights to a maximum altitude of 6,100 meters (20,000 feet). Mini sniffer-III was designed similar to the second model of the series with a larger fuselage to fly till 21.336 km, but it was possible to achieve an altitude of only 6.1 km [7].

AME was a rigid, non-folding model which was used to investigate the problems associated with low Reynolds number flight, one of the adverse conditions that any flight has to face on mars. This model was 22% of the size of the actual Mars airplane design. This model of Radio Controlled (R/C) airplanes commonly fly at Earth Sea level at Reynolds numbers similar to those that will be experienced at Mars. The actual performance of AME-1 was satisfactory. The need to generate more lift resulted in the use of long wings to increase the planform area, but this was associated with the problem of folding the long wings of AME to fit into the aeroshell which would be necessary for protection during the Martian atmospheric entry. Though the issue was fixed by multiple folds of the wing, that could be later deployed, the mechanism became very complex with each fold. On other hand shortening the wing reduced the planform area that increased the flight velocity to obtain the required lift, which in turn affected the flight power, and hence the fuel mass fraction was affected [5].

AME-2 was a near twin of AME-1, except that it could be folded and packaged in a mock entry capsule or aeroshell. This model included a total of 6 wing joints, one fuselage joint, and a tail boom release. The mock aeroshell was carried on board by a large radio-controlled mothership airplane (NASA-720) and dropped from altitudes between 300 and 500 m. These tests indicated that a much simpler deployment scheme was needed [5].

The observations and the results obtained from AME were used in building Kitty Hawk. The major modification was performed in the folding of Kitty Hawk wings, it had 2 wing hinges between the outer tip panels and the inner wing sections, and no fuselage folds. These modifications increased flight velocity and, since the airplane is a tailless design, it introduced flight control issues. Being smaller than AME, Kitty Hawk was less capacity for carrying heavier payloads. Kitty Hawk-2 was designed to fly a shorter traverse than AME and to carry fewer instruments [5]. To mark the 100th anniversary of the Wright brothers' flight two designs were proposed here to fly on Mars, but finally, the model which looked similar to AME was chosen and labeled as Kitty Hawk-3. With a low forward wing and a large tail, it had six hinge joints, one for the tail boom, one center pivot for the middle wing section, two for the tip panels, and two for the propeller. The wingspan of 2.6 m, an overall length of 1.5 m, and gross mass of 40 kg likely make this model a prototype of the smallest practical Mars airplane. The folded configuration of the Kitty Hawk-3 was very compact. Propulsion for Kitty Hawk-3 was achieved with the help of a propeller, which was driven by either an electric motor or a hydrazine heat engine [5].

Mother Goose vehicle was a combination of a glider, rover, and microbots. As per the data in the plan of action of its mission, the aeroshell after entering into the Martian atmosphere had to initially detach the glider and then subsequently the rover onto the surface. Pertaining the focus to only the glider, the only data that was found was regarding the glide time, which was around 3-4 hours, and a very rough sketch of its flight path [8,9].

The ARES mission had kicked off into action in 2002 to compete for the Mars Scout 2002 Launch Opportunity. The ARES-1 [10,11] vehicle concept was proposed for Phase-1 of the Mars Scout Program (in 2002) and then subsequently turned down citing improvements and was said to continue development. ARES-1 was then taken as the base for HADD-1 and ARES-2 vehicles and was then improved. With design refinements and concept maturation, the ARES-1 mission led to the most studied Mars airplane design, the ARES-2. ARES-2 [12,13] had a mass of 175 kg, including full-fuel, whereas the zero-fuel mass was found to be 127 kg.

Table 1: Specifications of ARES mission

Vehicle Mode	Robotic & Powered Airplane design
Propulsion type	Bi Propellent Rocket Engine (MMH + MON-3)
Flight Duration	Intended for 1 hour
Altitude	1 to 2 kms maximum

High Altitude Deployment Demonstrator (HADD)'s aim was to prove, how the basic conceptual vehicle ARES (ARES was still a concept vehicle in 2002) works and also to increase the preparedness of the ARES mission. Thus, HADD 1 and 2 were the testing vehicles of the major ARES project on which numerous experiments and demonstrations were conducted [14].

- HADD-1:
    1. The HADD-1 campaign was designed as the first in a series of test flights that raised the Technology Readiness Level to 8 for the critical entry, descent, and deployment phase.
    2. It was designed to be representative of the proposed ARES design with similar shape and other aspects, built to 50% scale.
- HADD-2 was a full-scale, structurally similar test drone with an exact outer mold line of the latest design cycle of ARES, namely ARES-2.

The flapping wing drone [15] design was pitched forward due to its advantages over other vehicles in terms of high lift coefficients. The entomopter (flapping wing drone) concept was expected to be a good contender for flight on Mars, because of its ability to generate lift similar to that as insects do on Earth, i.e., by the continuous formation and shedding of vortices on their wings. This vortex formation and shedding produce very high wing lift coefficients, typically of the order of 5 compared to the maximum lift coefficients of 1 to 1.2 for conventional aerofoils. But, the present-day advancement in this particular concept doesn't do justice for the aims to which the vehicle is intended.

The Mars Advanced Technology Airplane for Deployment, Operations, and Recovery (MATADOR), was a versatile, folding-delta-wing drone designed for deployment above the Martian surface. It had a wingspan of 4 m and could perform a steady-state flight at an altitude of 4 km with a flight speed of 180 m/s. The vehicle was designed based on the results obtained from the MAGE and AME missions. The design of MATADOR was found to be amenable to control in a highly stalled, low-speed condition, which was then adapted with the help of an Attitude Control System (ACS). The aircraft utilized a hydrazine-powered rocket engine rather than gravity, to increase flight speed during the glide. Its total mass was found to be about 65 kg [16].

Sky-Sailor was a micro glider with autonomous navigation and power generation systems. It had a scientific payload of 0.5 kg, and a wingspan of 3.2 m, and a total weight of around 2.5 kg. It a V-Tail and the wings had winglets at their extremities, to prevent vortex generation around the wingtip, which could decrease lift at the tip. It was powered by solar panels, but the batteries were used, only during the night flights or when the solar power generated was below the required threshold. The biggest advantage of this vehicle was its ability to travel large distances, i.e., it had an average flight time of 12 hours [17].

M-4 Minerva had a composite, foldable, swept, fixed-wing design that employed a twin-boom inverted V-tail. It was powered by pulsed, bi-propellant rockets, and had a wing area and span of 6.675 m2 and 6.18 m respectively. It had a gross weight of 141.5 kg, including a 48 kg fuel load and a 10 kg payload. The Minerva was designed to fly for up to 75 minutes covering a range of 620 km at a cruise speed of Mach 0.65 and up to 6 km altitude in the Martian atmosphere. A drop test vehicle, dubbed Cranfield Remote Aircraft for Technical Evaluation and Research (CRATER) was also constructed to accompany the vehicle, which was a 65% scale downed model of the Minerva vehicle. It had a 4.017 m wingspan, 2.82 m2 wing area, and a gross weight of 63.88 kg [18].

Both the ARMaDA and MAREA missions [19, 20] are based on a UAV design. The Advanced Reconnaissance Martian Deployable Aircraft (ARMaDA) mission concept proposed three identical UAVs operating in three different areas to have good coverage of the Martian surface. A radioisotope generator was used as a power source, which was a major advantage for increasing the lifetime of the mission. Thus, the only probable reason for mission termination would be mechanical failure. Each UAV had a mass of 63 kg and a wingspan of 8 m. They had a 3 blade electrically powered propeller with a diameter of 1.4 m. The UAVs main objective was to explore the Martian atmosphere.
The MAREA was designed with an inflatable wing structure, which was less complex and less susceptible to failure than a hinged wing construction, and also provided required aerodynamic performance. This UAV was proposed to study the characteristics of Martian soil, atmosphere, and magnetic field. The flight period was limited to 40 hours, i.e., one day and night cycle to investigate the changing Martian atmosphere. It had a total mass of 50kg and a wingspan of 8.8 m. The cruising speed of the UAV was 40m/s and the flight range was 5700 km. The main power system included solar cells fuel cell battery.

The MIRAGE mission aimed for scouting sites of scientific interest for future manned exploration. While having a cruise altitude of 1000 meters above Martian Sea level at Mach 0.45, its instruments had to collect atmospheric samples and obtain high-resolution measurements and images. Also, it employed the Co-Flow Jet (CFJ) airfoil, which could achieve extraordinarily high lift, with low drag and high stall margin to address the low density and Laminar regime of the Martian atmosphere. Thrust generation was by a propeller powered by Hydrogen fuel cells. It had landing gear with wheels derived from the Mars Exploration Rovers, thus, had the ability to roam on the ground and collect soil samples with a robotic arm equipped with a rock abrasion tool [21].

Argo-VII had a blended wing-body design with a constant aerofoil section used for the airframe of the aircraft. Assuming the mars flight condition at 2 km altitude and 0.65 Mach, it was designed for a maximum range lift co-efficient of 0.44, lift-to-drag ratio of 15.5, and endurance lift co-efficient of 0.76. The aircraft was designed to accommodate a vehicle gross weight of 175 kg at cruising conditions, where Zero-fuel weight was 116 kg with a total moment of 132 kg-m and Full-fuel weight was 164 kg, for which total moment was 192 kg-m. It had a wingspan and area of 6.66 m and 7.34 m2. The major advantage that was observed in this design was the usage of bi-propellant fuel (Bipropellant is a mixture of monomethyl-hydrazine (MMH) fuel and nitrogen tetroxide with a 3% mixed oxides of nitrogen additive (MON-3) oxidizer) and pulsed control thruster for propulsion, because it was light in mass, produced the required thrust, and upon that it was simple. Adding on to the advantage was its structure, which was made of a composite graphite-epoxy sandwich having a high strength to weight ratio [18,22].

Flapping wing design, also referred to as Exofly technology was believed to be well suited for the low atmospheric density of Mars because the performance, agility, and efficiency of flapping winged vehicles in low-density environments were found to be high for the Martian atmospheric conditions. Since the proposal of this technology, Delft University had been working on the development of the same, which resulted in the DelFly aerobot for use in Mars atmosphere. DelFly had a wingspan of 350 mm, length of 400 mm, a mass of 17 g, flying speed of 1.8 m/s, and flight time of 12 min. Whereas the second model which was developed by the same university, Delfly-II had a wingspan of 300 mm, length of 300 mm, mass of 15 g, flying speed of 30 km/hr (8.33 m/s), and flight time were 15 min horizontal, 8 min hovering. The advantages of the flapping wing design over the fixed-wing were that vehicles which utilized the latter design had to translate through the Martian atmosphere more quickly to generate adequate lift, making ground observations from such platforms more difficult and also landing and take-off likely to be unfeasible, also the propellers on such vehicles as well as rotor vehicles must generally rotate faster, which is dependent on the lowered sound speed in Mars atmosphere. Design must therefore potentially account for operation at a high Mach number [23,24].

Multicopter (Hexacopter/Octacopter) was the best among the four designs proposed by Pergola and Cipolla. The main components of the multicopter were an airframe, a set of propellers driven by brushless motors, a Li-ion battery pack, a flight control system which included the autopilot, an inertial measurement unit, and a communication and navigation module and the payload. It had ducted propellers which could save about 25-30 percent of power providing the same static thrust, and also the rotation speed was limited to 11,000 rpm. In addition, the maximum rotation speed had been defined by applying an upper limit of 0.80 to the maximum local Mach number, reached at blade tips, to avoid shock waves. The total mass of the drone was 6.52 kg for the hexacopter design and 7.25 kg for that of the octacopter, with the desired flight endurance of 30 minutes in hovering conditions. Among the four configurations of the hexacopter and octacopter proposed in [25], 6Xsol#14 had lower mass, smaller airframe dimension, and slightly higher endurance [22, 26].

Surrey Space Center had designed four electric vertical take-off and landing (VTOL) aircraft/aerobots for Martian exploration, in 2004. The first design, known as MASSIVA, weighing 15 kg, was a fixed-wing aircraft that incorporated two side-by-side rotors of 1.2 m diameter for VTOL capability. It was claimed to reach a cruise altitude of 70 km and have a payload capacity of 3.5 kg [22, 26].

The next design Halcyon, was larger than the previous design, it weighed 25 kg and was powered by solar cells. Even this used two variable pitch contra-rotating coaxial rotors to provide vertical thrust and two fixed pitch pusher propellers for horizontal thrust, which were designed to reach an altitude of 1km [22, 27].

The third design was named Hyperion, which attempted to reduce the total mass by using a large coaxial tilt rotor in the wing for both vertical and horizontal flights. Further modifications, which were recently done in 2016 included changing the rotor to a Y-4 Tilt Rotor (Y4TR) configuration, adding a coaxial cover, and implementing a blended wing body design [22]. The VTOL design would become the foundation for all future designs for Martian exploration, as it could take off and land easily.

Prandtl-m, abbreviated as Preliminary Research Aerodynamic Design to Land on Mars was a fixed-wing aircraft, whose design was inspired by an albatross' wing shape with very high efficiency. It had a wingspan of 60 cm and a weight of 1.5 Kg, whose expected flight time was around 10 minutes. It would glide from an altitude of 2000 feet and has a range of about 20 miles (~32 km) [22, 28].

The Canyon Flyer airplane was a propeller-driven subsonic airplane with two wing folds and a fuselage fold, which enabled stowage within an atmospheric-entry aeroshell. The fully deployed wingspan was 2.2 m. Both battery-powered electric motors and hydrazine-fuelled reciprocating engines were utilized for power.

In the first study, they produced a folding configuration of the wing and retracted propellers, which resulted in the airplane with a wingspan of 1.61 m and a chord of 0.35 m. This wing area supported a gross mass of 14.6 kg at the specified altitude, Mach number, and lift coefficient. Analysis of this configuration indicated that it was capable of carrying a total payload of about 8.1 kg for the desired 15-minute endurance, but the payload was reduced to about 5.2 kg with the required weight growth margin.

In the second study, they increased the span, which resulted in a dramatic increase in payload capability. The 0.3 m tip extensions resulted in a configuration with a wingspan of 2.2 m and a gross mass of 20 kg. This airplane is capable of carrying an 8.7 kg payload and the required 4.0 kg growth margin [29].

The MAGE [22,23] utilized a low-drag flying wing design with a wingspan of 9.75 m (32.0 ft) and weighed 135 kg. Utilizing a hydrazine-powered engine, its flight lasted for 3 hours covering a range of 1800 km, to fly at an altitude of the range 1000-9000 m.

2.2. Selection of Aircraft for Sample return:

From the literature survey of various existing aircraft designs for flight on Mars, the design that had sufficient payload capacity and ability to fly to the highest possible altitude would be considered as the basis of the design of aircraft for this proposed application. Thus, an electric VTOL aircraft, named Massiva, whose cruise altitude was observed to be 70 km [22, 26], was found to have the required characteristics. Because the major importance was given to the altitude up to which an aircraft would fly, and its ability to take off and land vertically without the requirement of the runway. Even though it was designed for a very less payload carrying capacity, a similar design for the required payload capacity which will be discussed in upcoming sections of the paper would be the most optimal solution especially for this proposed purpose for the air-launch system. Thus, an autonomous VTOL-aircraft, which can fly up to an altitude of 70km, with the required payload capacity would be the probable aircraft design that could be used here.

2.3. Calculation of reduced mass of the two-staged rocket:

As the only available design for a rocket-powered launch system on mars is Mars Ascent Vehicle (MAV), this was considered to be the design basis for our two-staged rocket which would be launched from a certain altitude (70km) from the autonomous aircraft. Based on the data available from [30], the total mass (Gross Lift-Off Mass) of MAV was observed to be 267.5 kg, of which the first stage fuel weighed 158.6 kg. The first stage of the MAV was designed to provide a thrust up to an altitude of 200 km before stage separation, since the launch, thus the rate of fuel consumption was approximately 0.793 kg/km altitude, considering the rate of fuel consumption to be linear.

In the case of an air-launching system as the designed aircraft will now carry the rocket system up to an altitude of 70km, thus the amount of fuel required in the first stage would be approximately 103.09 kg, as it will now have to provide thrust only for an altitude increase of 130 km. Thus, the mass of fuel saved would be 55.51 kg. Therefore, the total mass of the rocket to be carried by aircraft would be 211.99 kg.

2.4. Premise:

The detailed designing of the two-stage rocket and the autonomous VTOL air-launch aircraft, considering all the subsystems is not being done here, instead their specifications are only being proposed considering them to be similar to the available design of MAV and the Massiva aircraft respectively. This air-launch system would be much more efficient if both the Air-launch aircraft and the launch vehicle are optimized/designed specifically for this proposed purpose. i.e., a system specific design of both launch vehicle and aircraft has to be done considering all the constraints of the air-launching of the samples, for all the Martian conditions.

2.5. Design calculations of the VTOL aircraft for the required payload capacity:

As Massiva is considered as the basis for the design of the aircraft for the air-launch system, all the design constants are considered to be same as that of Massiva. Thus, the design characteristics of the wing of the autonomous aircraft for launching the rocket would be calculated considering the co-efficient of lift and aspect ratio of Massiva and autonomous air-launch aircraft to be same.

The co-efficient of lift is given by,

$$c_L = \frac{2L}{\rho_\infty v_\infty^2 A}$$

Let the cruise velocity of both Massiva and aircraft for Air-launch be same. As the lift co-efficient of both are considered to be equal,

$$\frac{2L_1}{\rho_\infty v_\infty^2 A_1} = \frac{2L_2}{\rho_\infty v_\infty^2 A_2}$$

We know that the required lift $L_1 = m_1 g_m$ and $L_2 = m_2 g_m$.

Therefore, the equation reduces to

$$\frac{m_1}{A_1} = \frac{m_2}{A_2}$$

From reference [27], m_1 and A_1 are 15 kg and 6 m^2 respectively. Also, the payload capacity of Massiva is equal to 3.5 kg [26]. Thus, the total mass of the aircraft, which would be an upgraded version of Massiva for carrying the payload, i.e., MAV of mass 211.99 kg (i.e., mass of the MAV) would be approximately,

$$m_2 = \frac{211.99 \times 15}{3.5} kg \approx 908.53\, kg$$

Therefore, the wing area of the autonomous Air-launch aircraft will be

$$A_2 = \frac{908.53 \times 6}{15} = 363.412\, m^2$$

The wing span can be calculated using the aspect ratio, which is equal to 12 [27]. The Aspect ratio is given by,

$$AR = \frac{s^2}{A_2}$$

$$12 = \frac{s^2}{363.412}$$

Therefore, wingspan of the autonomous aircraft for Air-launch would be, $s = 66.037\ m$.

Thus, the autonomous aircraft would have a mass of 696.54 kg and wingspan of 66.037m with VTOL capability, which will carry a two-stage rocket of mass 211.99 kg to air-launch it from an altitude of 70 km.

3. Conclusions:

3.1. Comparison between Air-launch and Ground launch system:

3.1.1. Advantages of Air-launch system over Ground-launch:

The Air-launch system has very high reusability, as it can launch the samples multiple times and also from different locations, which would be very difficult to achieve using the MAV ground launch system, because of its ability to travel long ranges in a very short period. Thus, it could be possible to gather samples from various Martian locations, which are exposed to different conditions. The aircraft can also map the surface from near altitudes, thus can also help efficiently analyze and decide on locations from which the samples should be collected. Launching this system from Earth onto mars is a one-time investment, which could be used for various mars exploration purposes even in the future days.

3.1.2. Disadvantages of Air-launch system over Ground-launch:

Based on the design of the aircraft proposed in this paper for the air-launch, it can be observed that its mass and size are very large. Thus, it could be very difficult to build and fly such huge systems in the Martian conditions. Also, it would be very difficult to launch such systems from earth, which leads to a conclusion that it would be much better to use a ground-launch system, as MAV is a small two-stage launch vehicle which would be much easier to be launched from Earth, considering that the only mission requirement is return of mars samples.

But, considering reusability and multifunctionality, the concept of Air-launch system would still be preferred to be efficient if its design is optimized for air-launch in Martian conditions.

4. Future Scope:

Designing the entire aircraft and two-stage/single-stage rocket powered launch vehicle for Air-launching, optimized for the Martian conditions. The future scope of this air-launch system would be to include a robotic system that can drill and collect the samples by hovering the aircraft at a particular location instead of using a rover for the same purpose.

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